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Hydrochemical Characteristics of Groundwater for Domestic and Irrigation Purposes in Dwarakeswar Watershed Area, India

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ABSTRACT

The Hydrochemical study was carried out in Dwarakeswar watershed area, Bankura and Purulia districts, West Bengal, India, with an objective of understanding the suitability of local groundwater quality for domestic and irrigation purposes. Groundwater samples have been collected from different villages within Dwarakeswar watershed area. The samples have been analysed to determine physical parameters like pH, EC, TDS and Hardness, the chemical parameters like Na, K, Ca, Fe, HCO_3, SO_4 and Cl. From the analysed data, some parameters like Sodium Absorption Ratio (SAR), Soluble Sodium Percentage (SSP), Residual Sodium Carbonate (RSC), Total Hardness (TH), Magnesium Absorption Ration (MAR) and Kelly's Ratio (KR) have also been determined. The distribution pattern of TDS and chlorides, which are the general indicators of groundwater quality reveals that on an average the ground water is fresh and potable except the ground water in and around Teghari, Gara and Satyatan Primary school where the groundwater is not potable and may affect the health of local population because concentration of TDS exceeds the desirable limits of 500 mg/L. The aerial distribution of Total Dissolved Solids (TDS) reveals that highest concentration is recorded at Gara and Teghri and the lowest concentrations is noted in Suburdih and Kalabani. SAR values were ranged between 0.09 - 0.54 meq/L in pre-monsoon and 0.01 - 0.24 meq/L in post-monsoon. It is evident from the whole sample set that the SAR value is *excellent* in all the samples. Hence, our findings strongly suggest that all the abstracted groundwater samples from the study area were suitable for irrigation. Results of analyses for physical and chemical parameters of groundwater in this area was found to be within the desirable Bureau of Indian Standards and World Health Organisation limits for drinking water.

Keywords: Groundwater Quality; Sodium Absorption Ratio (SAR); Irrigation Suitability; Drinking Water Suitability; Dwarakeswar Watershed

1. Introduction

Water is the most important resource for human existence. Ensuring access to cheap and clean drinking water is emerging as one of the most difficult challenges of this century. In rural side, there is an acute crisis of potable water with some of the water pockets containing excess salinity, hardness, fluoride, arsenic, or harmful pathogens which cause several health problems.

Water being a universal solvent has been and is being utilized by man kind time and now. Of the total amount of global water, only 2.4% is distributed on the main land, of which only a small portion can be utilized as fresh water. The available fresh water to man is hardly 0.3% - 0.5% of the total water available on the earth and therefore, its judicious use is imperative [1]. The fresh water is a finite and limited resource [2]. The utilization of water from ages has led to its over exploitation coupled with the growing population along with improved standard of living as a consequence of technological innovations [3, 4]. This contamination of groundwater is not away from the evils of modernization. Therefore, quality of groundwater is deteriorating at a faster pace due to pollution ranging from septic tanks [5,6], land fill leachates, domestic sewage [7-9], agricultural runoff/agricultural fields [10-14] and industrial wastes [3,4,8,15]. Contamination of groundwater also depends on the geology of the area and it is rapid in hard rock areas especially in limestone regions where extensive cavern systems are below the water table [16]. This is a common feature, not only in developed countries but also in developing countries like India. The changes in quality of groundwater response to variation in physical, chemical and biological environments through which it passes [17].

Groundwater is normally used directly in rural areas

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without proper monitoring and treatment. Groundwater may also become contaminated by the agrochemical products used for irrigation. The groundwater quality in southern part of the country namely Chennai, Kancheepuram and Chengalpet, has been studied earlier [18-23]. However, no such studies have been carried out in the Dwarakeswar watershed region of West Bengal, pertaining to groundwater quality. The suitability of groundwater for domestic and irrigation purposes thus had to be determined based on the presence of major ions in the groundwater of this region. The present study, which was carried out in 2009, will serve as baseline data for comparing future groundwater quality.

2. Study Area

The study area comprises of Precambrian crystalline and recently deposited alluvium connected by an intervening tract. The Dwarkeswar watershed with a semi-elliptical shape occupies the Kashipur block which is situated in northeastern part of Puruliya district, but the major part of the Dwarkeswar watershed is situated in a part of Chhatna block of Bankura district of West Bengal state, India.

The Dwarkeswar watershed is bounded by longitudes 86˚51'E and 87˚0'E and latitudes 23˚16'N to 23˚50'N. and is covered in the Survey of India Toposheet numbers 73 I/11, 73 I/15 and 73 I/16 on 1:50,000 scale The Dwarkeswar watershed lies in between the Damodar basin (to the north) and Kangsabati basin (to the south). The Dwarkeswar river is one of them largest river which rises in the hilly terrain of Puruliya district and flows from northwest to south east, almost dividing the Chhatna Block into two equal halves. The Dwarkeswar flows east up to Kashipur and then South east from 86˚44'E. where it receives the Bekon Nala flowing east-south east. The other left bank tributary Dangra Nala has scissored the undulating surface into mesh of gully before entering the Bankura district as the Kumari Nala. The right bank tributaries of the Dwarkeswar river are the Futuari Nala flowing north east, Dudhbhaiya Nala flowing north and Arkasa Nala flowing east the last two having their sources near Hura block. The Arkasa turn north east in Bankura district where from its confluence, the Dwarkeswar River becomes a perennial stream. Dwarkeswar river and all above mentioned tributaries dry up during the cold and hot seasons. Gully erosion all along their channels is a very conspicuous feature. In its lower course the Dwarkeswar river is known as Rupnarayan.

3. Materials and Methods

Groundwater samples were collected in polythene bottles of 2 liters capacity for physicochemical analysis after pumping out sufficient quantity of water from the tubewells such that, the sample collected served as a representative sample. The sample locations are shown in **Figure 1**. The bottles were completely filled before sealing tightly. All particulars regarding water sample were written in the field itself, immediately after sampling, and tagged to the sample bottle. Special treatment are given for preservation, fixation and handling of water samples before analysis so that the quality of water is not changed and many of heavy metal ions normally present in small quantities in natural water remain in water till the sample is analyzed. High temperature is avoided in the storage room. Only high pure (Analytical IR Grade) chemicals and double-distilled water was used for preparing solutions for analysis. Physical parameters like pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS) were determined at the site with the help of field kit.

The groundwater quality was assessed by the analysis of chemical parameters such as chlorides sulphates, bicarbonates, iron, calcium, magnesium and sodium using standard methods [24]. The results of the physicochemical parameters of the samples are shown in **Table 1**.

4. Results and Discussions

4.1. Hydrogeology

Hard rocks are mainly composed of metamorphic and magmatic rocks of Precambrian or Archean ages. The importance of hard rock aquifers from groundwater point of view differs from place to place, depending on various factors, but mainly on the overall availability and demand of water. Hard rock aquifers generally occupy the upper tens of meters of the subsurface profile [25]. The hydrogeologi cal characteristics of the weathered mantle and underlying bedrock depend mainly on the weathering and erosional processes [26,27].

Hydrogeological studies reveal that ground water occurs in two distinct group of aquifers—the upper one is weathered residuum of mica-schists and associated rocks, restricted within 10 to 15 m below ground level and deeper

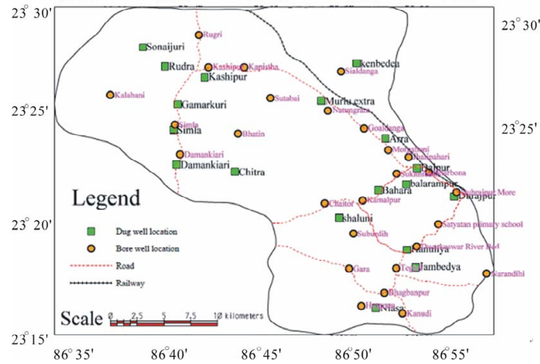


Figure 1. Map of the study area showing sample locations.

Table 1. Report of physico-chemical parameters of the studied groundwater samples (pre-monsoon and post-monsoon, 2009).

Sample No.	Location Name	Physical Parameters								Chemical Parameters													
										Anions						Cations							
		pH		EC (μS/cm)		TDS (mg/L)		Hardness (mg/L)		Cl (mg/L)		HCO_3 (mg/L)		SO_4 (mg/L)		Fe (mg/L)		Mg (mg/L)		Ca (mg/L)		Na (mg/L)	
		pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
A1	Dubrajpur More	7.9	7.1	340	700	218	257	210	230	70	60	260	220	76.1	34.1	0.80	0.25	4.32	2.07	22.74	30.06	7.53	1.27
A2	Satyatan p.school	7.7	7.1	190	300	122	122	100	130	40	40	110	170	47.5	76.3	0.50	0.8	3.92	4.83	9.98	59.94	6.37	5.21
A3	Dwarkeswar R. Bed	7.9	6.4	180	400	115	122	90	1070	20	30	110	170	12.2	42.9	0.10	0.4	4.20	4.18	14.40	46.43	6.57	3.72
A4	Teghri	6.7	6.6	1850	3400	1184	1365	1030	750	640	580	180	280	53.7	76.4	0.50	0.8	5.20	4.71	53.74	113.24	11.47	4.16
A5	Gara	7.0	6.5	1940	2400	1242	948	1190	200	660	340	210	310	24.4	127.3	0.30	1.3	5.16	3.12	52.55	98.53	11.57	2.03
A6	Suburdih	6.4	6.5	130	300	83	130	90	330	40	110	130	190	41.6	116.5	0.50	1.2	3.34	3.51	6.39	79.96	5.35	4.07
A7	Kamalpur	7.0	7.0	480	900	307	334	280	200	30	40	430	350	127.8	138.4	3.00	3.0	4.81	3.71	21.61	40.06	6.99	4.59
A8	Sukhnibash	6.1	6.4	450	900	288	333	200	310	90	110	140	150	153.1	43.5	3.00	0.5	4.39	3.62	18.19	36.53	10.01	7.83
A9	Jhatipahari	6.1	6.4	590	400	378	327	350	210	110	100	150	230	98.5	21.6	3.00	0.2	4.87	3.78	24.02	30.07	8.10	6.87
A10	Morgaboni	6.3	6.5	220	500	141	177	140	210	20	50	160	230	26.3	25.9	0.30	0.2	4.21	3.67	12.41	84.57	6.57	5.71
A11	Kharbona	7.5	6.6	590	1300	378	495	400	420	80	110	780	350	37.2	28.5	0.30	0.3	4.71	4.13	30.84	59.96	9.34	7.52
A12	Narandihi	7.2	7.1	460	800	294	360	240	270	70	50	240	250	86.7	27.4	0.80	0.2	4.69	3.41	23.69	74.86	6.61	6.32
A13	Kanudi	6.5	6.5	170	300	109	104	90	150	10	40	130	180	152.4	31.5	1.20	0.3	4.32	4.81	8.09	79.53	5.23	7.26
A14	Bhagbanpur	7.1	7.1	220	400	141	144	110	200	20	20	120	170	23.6	27.5	0.30	2.0	4.24	4.83	10.68	103.27	5.22	5.02
A15	Hutgram	6.6	7.1	220	400	141	153	100	140	10	30	160	210	47.9	36.9	0.50	3.0	4.80	4.88	9.64	214.23	6.50	7.53
A16	Chaitor	6.9	6.9	780	1100	499	442	460	430	160	120	250	290	42.2	11.6	0.50	0.3	4.81	3.79	44.29	43.76	6.99	6.52
A17	Goaldanga	7.4	6.4	880	1500	563	542	460	450	220	200	160	170	59.4	24.7	0.50	0.3	4.85	3.92	41.06	36.29	8.65	5.74
A18	Kalabani	6.6	6.8	350	200	1340	92	1010	190	570	30	290	180	73.6	35.7	0.70	0.1	4.96	2.07	110.64	43.87	3.94	1.04
A19	Damankiari	6.4	6.6	130	900	438	325	380	330	90	90	140	210	36.3	39.6	0.30	3	3.76	3.52	36.42	73.65	3.58	3.68
A20	Simla	6.8	6.4	120	1600	447	633	470	460	127	310	310	230	43.1	28.5	0.40	1.2	4.13	2.16	46.73	68.27	3.97	5.83
A21	Kashipur	6.6	6.2	160	800	540	283	490	260	220	110	190	180	16.3.3	21.6	0.20	1.2	4.76	2.23	38.79	53.94	8.37	4.39
A22	Rugri	6.6	6.9	210	1700	1154	622	982	660	360	250	350	330	56.8	24.73	0.76	1.2	2.86	2.38	94.68	57.73	5.27	6.84
A23	Kapistha	6.5	6.9	280	200	30	94	160	120	310	30	320	140	112.7	20.05	0.80	0.1	3.72	1.93	79.37	53.26	3.94	6.38
A24	Bhatin	6.9	6.6	207	1500	376	574	385	500	170	170	340	210	36.3	22.73	0.30	1.2	3.84	2.34	58.69	41.37	5.82	4.72
A25	Sutabai	6.7	6.6	210	1800	174	721	480	500	140	250	280	180	18.7	17.63	0.30	0.5	4.86	3.26	114.37	68.38	5.86	5.96
A26	Natungram	7.2	6.8	50	900	36	353	140	220	62	90	130	280	163.9	46.38	2.07	0.4	4.87	3.17	78.41	61.94	6.48	3.46
A27	Sialdanga	7.1	6.4	40	2500	148	1008	130	800	68	400	130	390	183	29.7	2.04	0.2	4.96	2.06	78.41	52.17	6.48	5.29

one represented by fractures occurring at varying depth between 30 m to 150 m below ground level. Both the aquifers are the repositories of ground water within secondary porosities developed due to geological process. The first aquifers is developed by due wells and solely used for drinking and other domestic purposes. The second aquifer (fracture zones) being exploited for industrial water supply are also used for drinking water supply.

Ground water is hidden from view beneath the land surface, it can only be directly observed through monitoring wells. In order to assess water level configuration of different aquifers, hydrogeological studies have been carried out. The upper aquifer is tapped by open dug wells and mainly used for domestic consumption. Bore wells in different industries withdrawal water from the deeper fracture zones, which occurs under semi-confined to confined conditions.

Altogether 27 nos. of bore wells and 24 nos. of dug wells were marked and monitored for having an idea of water table in pre- and post-monsoon 2009 (**Figure 2**). Water table studies indicate that groundwater level varies in between 95.94 mts to 193.17 mts. in pre-monsoon. Highest value of water table is recorded in Damankiari area. In post-monsoon water table studies indicate that groundwater level varies in between 98.41 m to 195.70 m. Highest value of water table is recorded in Kalabani area (**Figures 2(a)** and **(b)**).

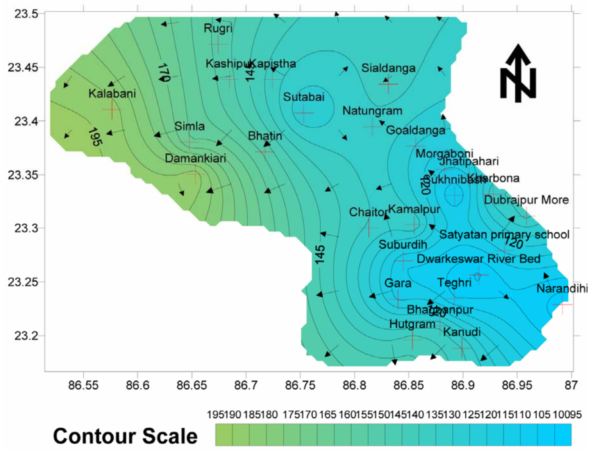
In case of dug well water table varies between 105.05 mts to 193.88 mts in pre-monsoon and in post-monsoon it varies between 108.25 mts to 196.88 mts. Lowest value of water table is recorded in Hanuliya area 105.5 mts and 108.25 mts during pre-and post-monsoon respectively. Water table contour map of dug well indicates the formation of a cone of depression in the area surrounding Teghori and Jambani in pre- and post-monsoon time (**Figures 3(a)** and **(b)**)

4.2. Major Ion Chemistry and Spatial Distribution

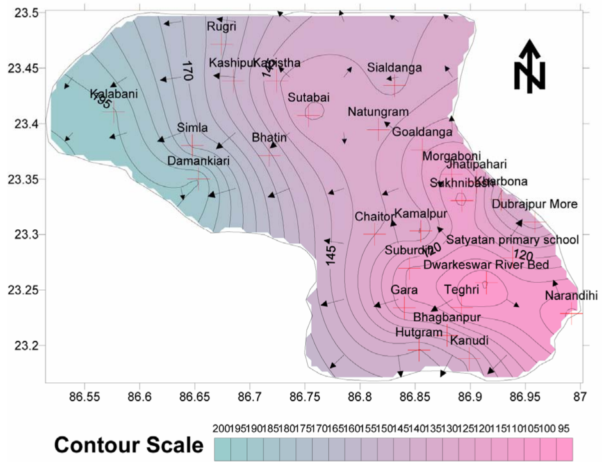
The pH values of the groundwater varied from 6.1 to 7.9 with an average value 6.9 (pre-monsoon) while the pH values range between 6.2 to 7.1 (post-monsoon) with an average value 6.7. This indicates that water is neutral in nature. The variation in pH values both in pre- and post-monsoon periods are shown in **Figures 4(a)** and **(b)**.

In the study area, the value of electrical conductivity varied from 40 - 1940 μS/cm with an average value of 423.96 μS/cm during pre-monsoon while the value ranged between 200 - 3400 μS/cm with an average of 1040.74 μS/cm during post-monsoon period (**Figures 5(a)** and **(b)**).

In the study area, the concentration value of TDS

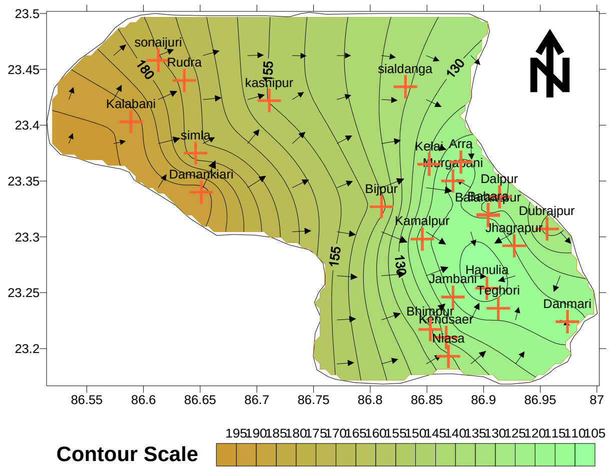


(a)

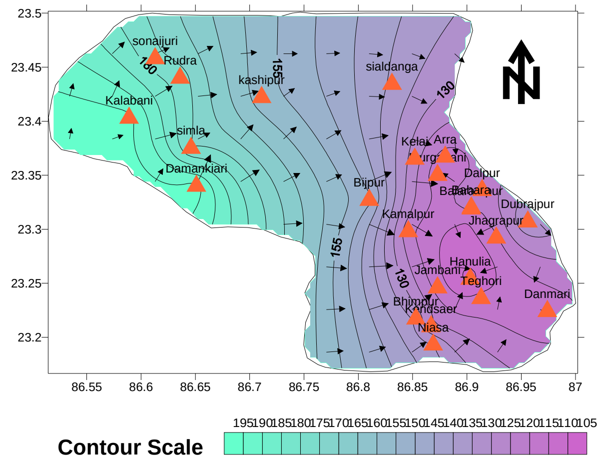


(b)

Figure 2. Water table contour map of the study area bore well: (a) pre-monsoon; (b) post-monsoon.



(a)



(b)

Figure 3. Water table contour map of the study area dug well: (a) pre-monsoon; (b) post-monsoon.

ranged between 30 to 1340 mg/L (pre-monsoon) with the mean value of 403.18 mg/L. The TDS value ranged between 92 to 1365 mg/L (post-monsoon) with the mean value of 409.63 mg/L. The TDS of the study area falls within the WHO (2004) Standard of 1000 mg/L. The water is thus good for human consumption (domestic) and agricultural purposes (**Figures 6(a)** and **(b)**).

The total hardness expressed as $CaCO_3$ is above the desirable limit (300 mg/L) and allowable limit is (600 mg/L). The hardness is temporary in nature and can be removed by boiling. The water samples of the study area show variation from 90 - 1190 mg/L (pre-monsoon) with an average value of 376.55 mg/L while the value of hardness ranged between 120 - 1070 mg/L during post-monsoon period with the average value of 360.74 mg/L (**Figures 7(a)** and **(b)**)

The hardness in water is derived from the solution of carbon dioxide released by bacterial action in the soil, in percolating rain water. Low pH conditions develop and lead to the dissolution of insoluble carbonates in the soil and in limestone formations to convert them into soluble bicarbonates. Impurities in limestone, such as sulfates, chlorides and silicates, become exposed to the solvent action of water as the carbonates are dissolved so that they also pass into solution. The general acceptance level of hardness is 300 mg/L, although WHO [23] has set an allowable limit of 600 mg/L. The spatial distribution pattern of physical parameters like pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS) during the study period are shown in **Figures 4(a)** and **(b)**, **Figures 5(a)** and **(b)** and **Figures 6(a)** and **(b)**.

In the study area, the concentration of chloride is found to vary between 10 - 660 mg/L with the average value of 163.2 mg/L in pre-monsoon while during post-monsoon the value ranged between 20 - 580 mg/L with the mean value of 139.3 mg/L (**Figures 8(a)** and **(b)**). The mean values during pre- and post-monsoon time are much below the maximum allowable concentration of 250 mg/L [28]. WHO has set standards of 200 - 500 mg/L for chloride in drinking water. Too much of chloride leads to bad taste in water and also chloride ion combines with the Na (that is being derived from the weathering of

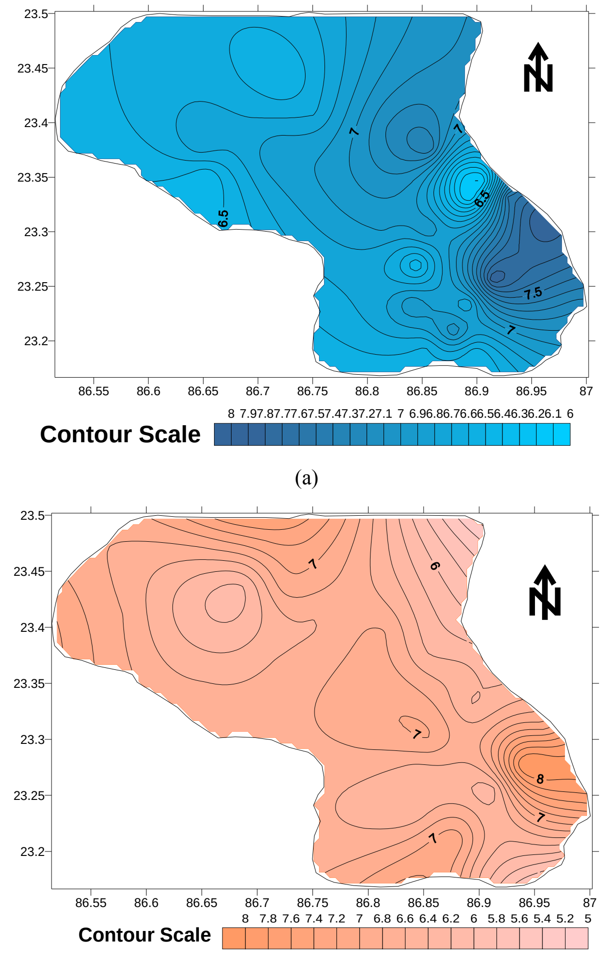


Figure 4. pH contour map: (a) pre-monsoon; (b) post-monsoon.

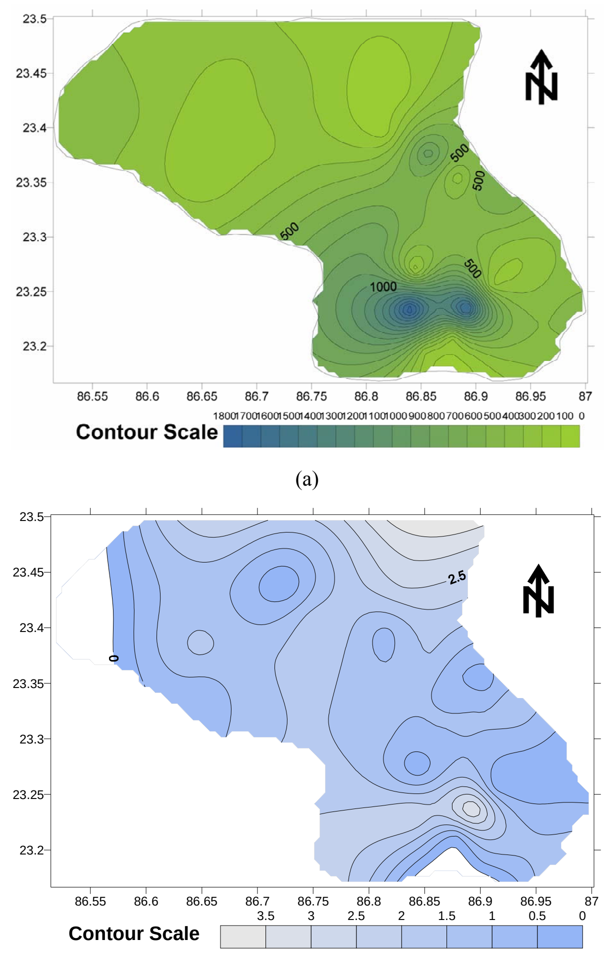


Figure 5. Specific conductivity contour map: (a) pre-monsoon; (b) post-monsoon.

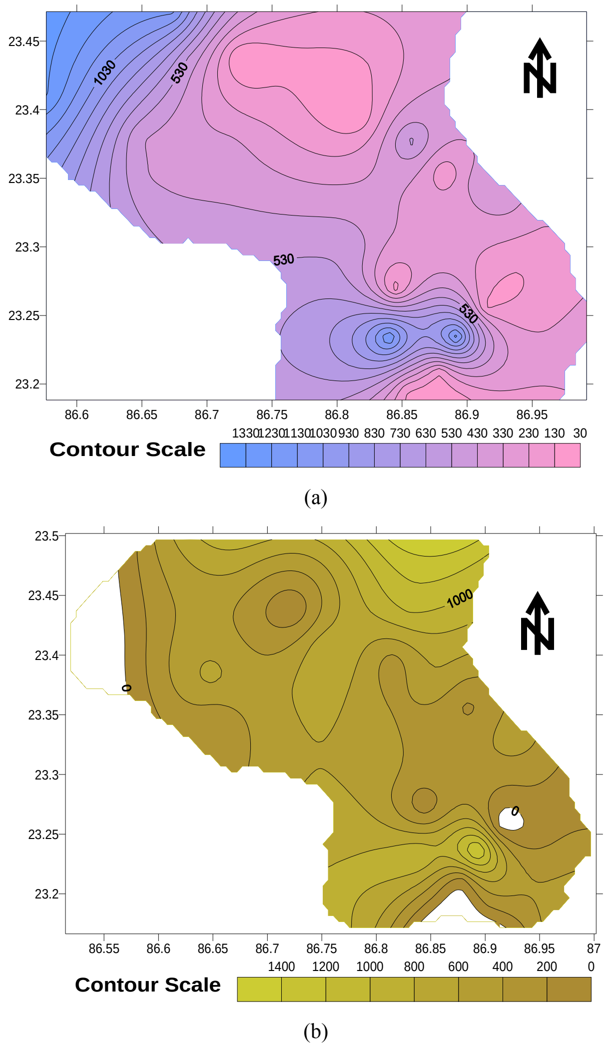


Figure 6. Total dissolved solids contour map: (a) pre-monsoon; (b) post-monsoon.

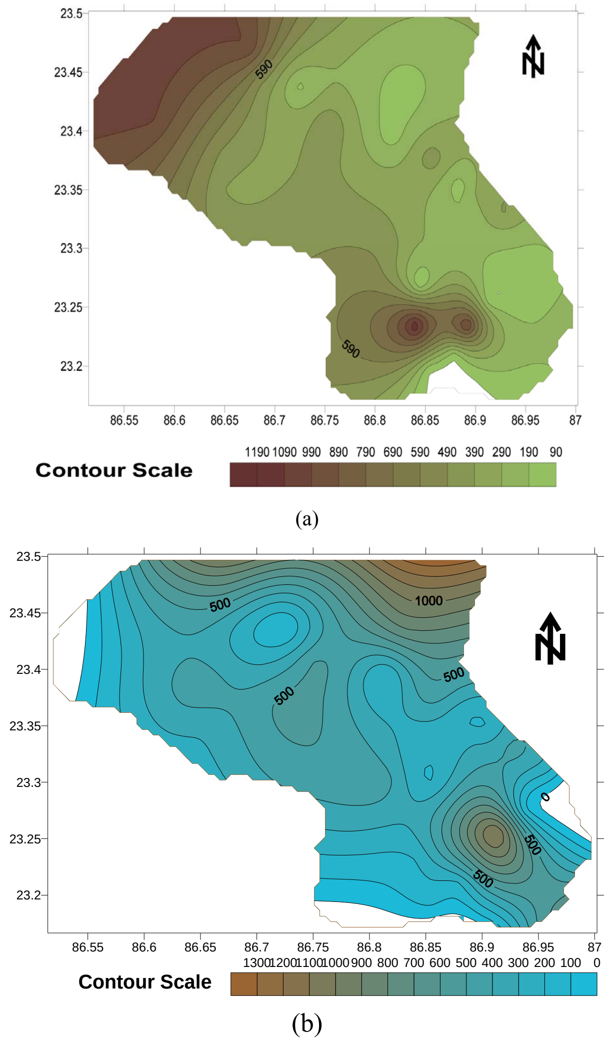


Figure 7. Hardness contour map: (a) pre-monsoon; (b) post-monsoon.

granitic terrains) and forms NaCl, whose excess presence in water makes it saline and unfit for drinking and irrigation purposes. Here too, as exhibited by contours, the chloride value decreases during post-monsoon.

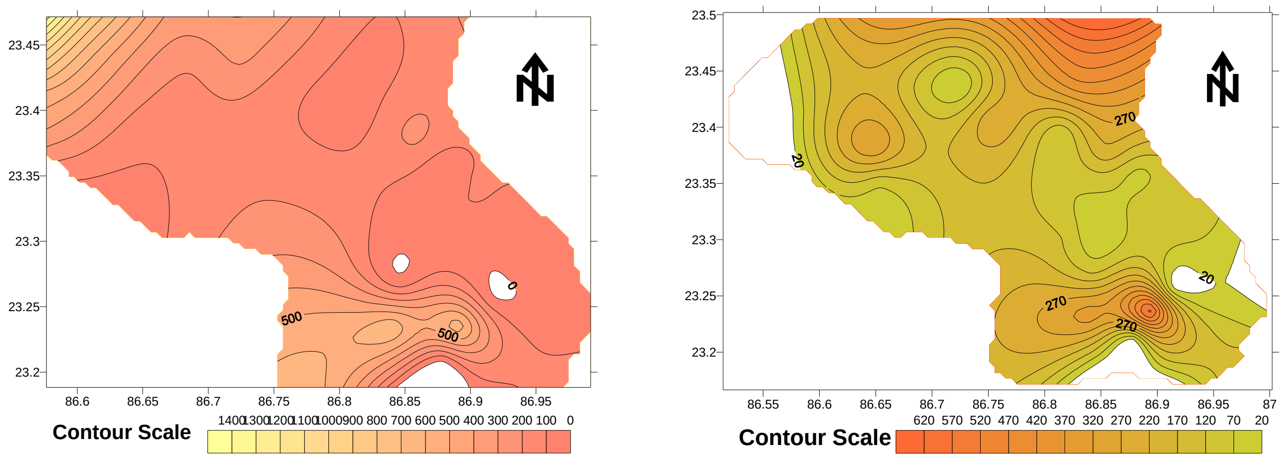
Bicarbonate ion varied from 110 to 780 and with mean value of 229.6 mg/L during pre-monsoon and 140 to 390 mg/L with average value of 231.5 mg/L in the groundwater samples of post-monsoon season period (**Figures 9(a)** and **(b)**).

The sulfate ion causes no particular harmful effects on soils or plants; however, it contributes to increase the salinity in the soil solution. Sulphur is an essential element in plant nutrition and in the form of sulphate it is readily available to plants. Sulfate ion varied from 12.2 to 183.0 mg/L during the pre-monsoon and from 11.6 to 138.4 mg/L in post-monsoon seasons (**Figures 10(a)** and **(b)**).

Calcium and magnesium ions present in groundwater of nearby coastal areas are derived from leaching of limestone, dolomite, gypsum and anhydrites whereas calcium ions may derive from cation exchange processes [29]. Calcium in normal potable ground water has concentration between 10 and 100 ppm which has no known effect on the health of human or animals. In the present study, the concentration of Calcium ranged from 6.39 to 114.37 mg/L during pre-monsoon while it varied from 30.06 to 214.23 mg/L during post-monsoon periods. The spatial distribution of calcium during the study period is shown in **Figures 11(a)** and **(b)**.

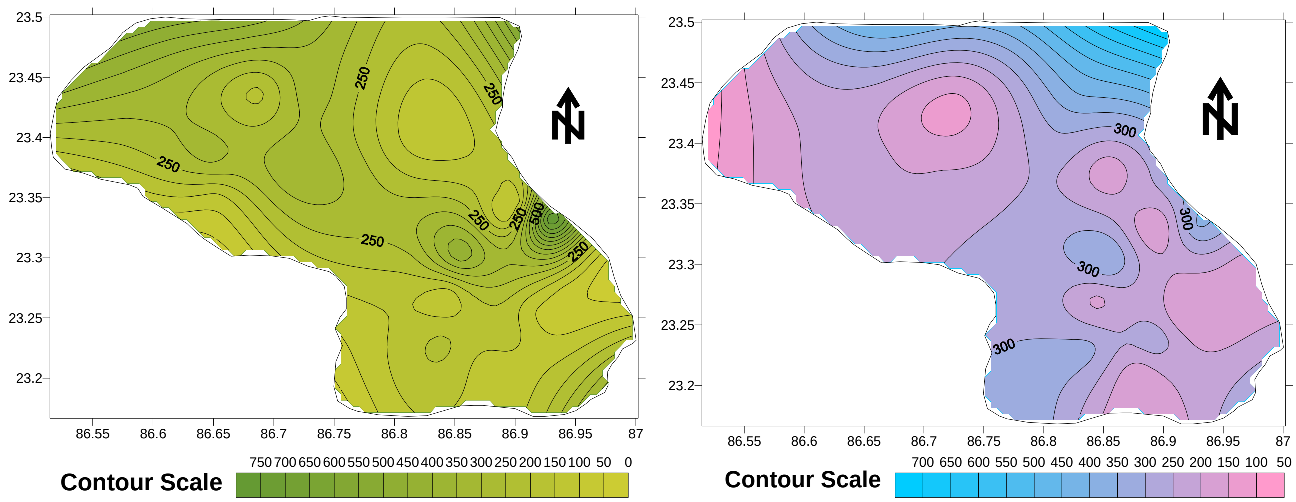
In the present study, the concentration of Magnesium ranged from 2.86 to 5.2 mg/L during pre-monsoon while it varied from 1.93 to 4.88 mg/L during post-monsoon periods (**Figures 12(a)** and **(b)**).

The adverse effect of sodium on the soil was more closely related to the ratio of sodium to the total cations in the irrigation water than to the absolute concentration



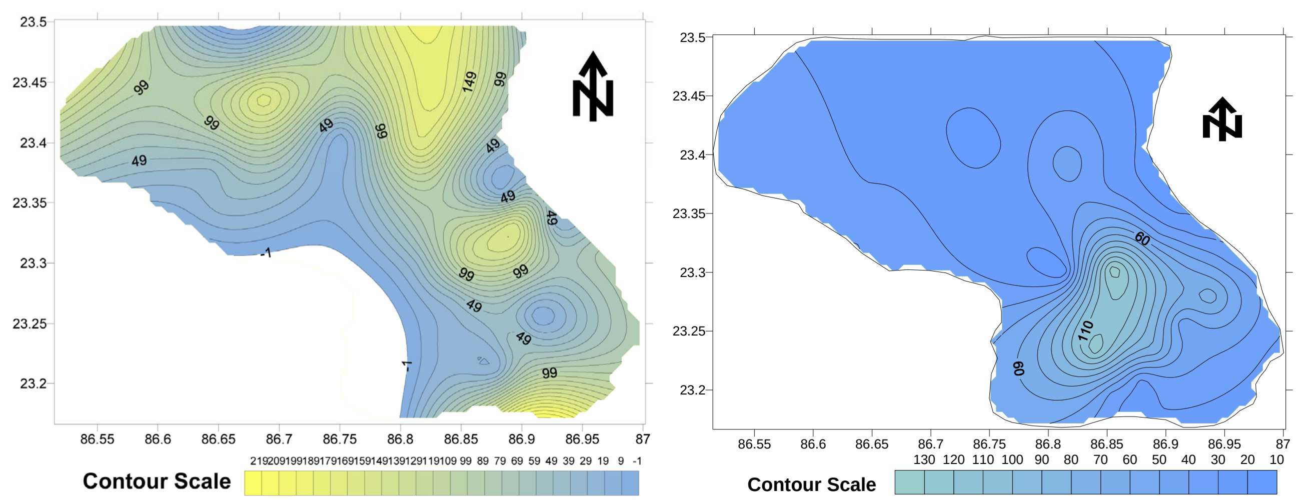
(a) (b)

Figure 8. Chloride contour map: (a) pre-monsoon; (b) post-monsoon.



(a) (b)

Figure 9. Bi-carbonate contour map: (a) pre-monsoon; (b) post-monsoon.



(a) (b)

Figure 10. Sulphate contour map: (a) pre-monsoon; (b) post-monsoon.

of sodium. It has now been recognized that as percent of sodium increases in the soil solution larger quantities are absorbed during the exchange, replacing calcium and magnesium, thus resulting in alkali soil. The concentration of sodium in the water samples collected vary from 3.58 to 11.57 mg/L (pre-monsoon) and 1.04 to 7.83 mg/L (post-monsoon) (**Figures 13(a)** and **(b)**).

Iron is an essential element in human [30]. Although iron has little concern as a health hazard, it is still considered as a nuisance in excessive quantities [31]. It causes staining of clothes and utensils. It is also not suitable for processing of food, beverages, dyeing, bleaching etc. The concentration limits of iron in drinking water ranges between 0.3 mg/L (maximum acceptable) and 1.0 mg/L (maximum allowable) (**Figures 14(a)** and **(b)**). The concentration of iron in the water samples collected vary from 0.1 to 3.0 mg/L both in pre- and post-monsoon.

During pre-monsoon, most of the ion concentrations are high compared to the post-monsoon period and this may be due to the dissolution of minerals [32,33].

4.3. Irrigational Suitability

Water for agricultural purposes should be good for both plant and animals. Good quality of waters for irrigation is characterized by acceptable range of:

1) The Sodium Adsorption Ratio (SAR);
2) The Soluble Sodium Percentage (SSP);
3) The Residual Sodium Carbonate (RSC);
4) The Magnesium Adsorption Ratio (MAR);
5) The Kellys Ratio (KR);
6) The Permeability Index (PI).

All these parameters are calculated and are presented in **Table 2**.

The Sodium Adsorption Ratio (SAR) was calculated by the following equation given by Richards [34] as:

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca}+\mathrm{Mg}}{2}}} \quad (1)$$

where, all the ions are expressed in meq/L.

Sodium Adsorption Ratio (SAR) also influences infiltration rate of water. So, low SAR is always desirable. In the studied samples, SAR values were ranged between 0.09 - 0.54 meq/L in pre monsoon and 0.01 - 0.24 in post-monsoon. It is evident from the whole sample set that the SAR value is *excellent* in all the samples. (**Figure 15**) Hence, our findings strongly suggest that all the abstracted groundwater samples from the study area were suitable for irrigation.

The Soluble Sodium Percentage (SSP) was calculated by the following equation Todd [35]:

$$\mathrm{SSP} = \frac{(\mathrm{Na}+\mathrm{K})\times 100}{(\mathrm{Ca}+\mathrm{Mg}+\mathrm{Na}+\mathrm{K})} \quad (2)$$

where, all the ions are expressed in meq/L. Wilcox [36] has developed a table for classification of irrigation water with reference to Na percentage and EC value (umhos/cm) (**Figure 16**).The Soluble Sodium Percentage (SSP) values were found from 2.78 meq/L at Kalabani to 28.01 meq/L at Suburdih in pre monsoon and 1.52 meq/L at Gara and 13.82 meq/L at Sukhnibash in post monsoon.

The Residual Sodium Carbonate (RSC) was calculated according to Gupta and Gupta [37]:

$$\mathrm{RSC} = (\mathrm{CO_3}+\mathrm{HCO_3}) - (\mathrm{Ca}+\mathrm{Mg}) \quad (3)$$

where, RSC and the concentration of the constituents are expressed in meq/L. The Residual Sodium Carbonate (RSC) values were found from –2.2 meq/L at Sialdanga 5.57 meq/L at Kamalpur in pre-monsoon and –7.67 meq/L at Gara and 3.62 meq/L at Sukhnibash in post monsoon.

Total Hardness (TH) was calculated by the following equation Raghunath [38]:

$$\mathrm{TH} = (\mathrm{Ca}+\mathrm{Mg})\times 50 \quad (4)$$

where, TH is expressed in meq/L and the concentrations of the constituents are expressed in meq/L. Total Hardness (TH) values were found from 29.89 meq/L at Suburdih 297 meq/L at Kalabani in pre-monsoon and 83.5 meq/L at Dubrajpur 555.5 meq/L at Hutgram in post-monsoon.

Magnesium Adsorption Ratio (MAR) was calculated by the equation Raghunath [38] as:

$$\mathrm{MAR} = \mathrm{Mg}\times 100/(\mathrm{Ca}+\mathrm{Mg}) \quad (5)$$

where all the ionic concentrations are expressed in meq/L. Magnesium Adsorption Ratio (MAR) values were found from 4.63 at Rugri 47.09 at Kanudi in pre-monsoon and 3.60 at Hutgram and 17.12 at Jhatipahari in post-monsoon.

The Kelly's Ratio was calculated using the equation Kelly [39] as:

$$\mathrm{KR} = \mathrm{Na}/(\mathrm{Ca}+\mathrm{Mg}) \quad (6)$$

where, all the ionic concentrations are expressed in meq/L. The Kelly's Ratio (KR) values were found from 0.02 at Kalabani 0.34 at Sukhnibash in pre-monsoon and 0.01 at Kalabani,Gara 0.16 at Jhatipahari in post-monsoon.

Permeability Index

Doneen [40] has evolved a modified criterion based on the solubility of salts and the reaction occurring in the soil solution from cation exchange for estimating the quality of agricultural waters. According to him, soil permeability, as affected by long-term use of irrigation water, is influenced by 1) total dissolvesolid 2) sodium contents, 3) bicarbonate contents, and the soil. To incorporate the first three items Doneen [40] has empirically developed a term called, "Permeability Index" after conducting a series of experiments for which he has used

Table 2. Resulting parameters (pre-monsoon and post-monsoon, 2009) of the studied groundwater samples.

Sample No.	Location Name	SAR		PI		SSP		MAR		TH		RSC		KR	
		pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
A1	Dubrajpur More	0.39	0.05	131.11	112.79	17.95	2.90	24.05	1.017	74.85	83.5	2.77	1.93	0.22	0.02
A2	Satyatan p. school	0.93	0.16	146.91	52.07	25.12	6.09	39.56	11.79	41.28	169.5	0.98	–1.21	0.34	0.06
A3	Warkeswar R. Bed	0.38	0.13	120.13	64.53	21.07	5.67	32.71	12.78	53.50	133	0.73	0.12	0.27	0.06
A4	Teghri	0.39	0.1	61.25	37.23	13.78	2.88	13.89	6.44	156.02	302.5	–0.17	–1.46	0.16	0.02
A5	Gara	0.40	0.05	66.24	44.29	14.13	1.52	14.06	5.01	152.88	259	0.39	–0.1	0.16	0.01
A6	Suburdih	0.43	0.11	203.8	43.37	28.01	3.40	46.56	6.77	29.89	214	1.53	–1.17	0.39	0.03
A7	Kamalpur	0.24	0.01	165.74	103.61	17.02	7.63	27.06	13.04	74.07	115	5.57	3.43	0.21	0.08
A8	Sukhnibash	0.54	0.03	114.01	121.79	25.44	13.82	28.69	14.15	63.77	106	1.02	0.33	0.34	0.16
A9	Jhatipahari	0.39	0.3	98.02	105.23	17.98	13.80	25.26	17.12	80.34	90.5	0.85	1.96	0.22	0.16
A10	Morgaboni	0.40	0.16	151.57	45.79	22.73	5.04	36.12	6.63	48.57	226	1.65	–0.75	0.29	0.05
A11	Kharbona	0.40	0.24	170.13	74.24	17.35	8.76	20.29	10.21	96.73	166.5	10.85	2.4	0.21	0.09
A12	Narandihi	0.31	0.19	122.16	53.37	15.13	6.29	24.84	6.96	78.5	201	2.36	0.07	0.17	0.06
A13	Kanudi	0.36	0.21	170.1	43.16	22.93	6.62	47.09	9.15	38.23	218.5	1.37	–1.42	0.30	0.07
A14	Bhagbanpur	0.33	0.12	146.24	32.4	20.73	3.63	39.82	7.19	44.37	278	1.08	–2.78	0.26	0.03
A15	Hutgram	0.42	0.13	136.33	18.98	24.27	2.79	45.35	3.60	44.10	555.5	1.74	–7.67	0.32	0.02
A16	Chaitor	0.26	0.21	79.76	88.4	10.41	9.78	15.33	12.14	130.77	124.5	1.48	2.26	0.12	0.10
A17	Goaldanga	0.33	0.23	70.44	80.16	13.27	10.12	16.45	15.02	122.86	106.5	0.17	0.65	0.15	0.11
A18	Kalabani	0.09	0.03	38.29	72.91	2.78	1.66	6.90	7.20	297	118	–1.19	0.59	0.02	0.01
A19	Damankiari	0.14	0.11	72.8	48.66	6.57	3.87	14.55	7.30	106.5	198.5	0.16	–0.53	0.07	0.04
A20	Simla	0.14	0.18	85.21	57.03	5.98	6.51	12.73	5.01	133.5	179.5	2.41	0.9	0.06	0.06
A21	Kashipur	0.33	0.15	79.1	62.09	13.43	6.20	16.81	6.27	116	143.5	0.79	0.08	0.15	0.06
A22	Rugri	0.14	0.23	50.38	77.67	4.24	8.63	4.63	6.18	248	153.5	0.77	2.33	0.04	0.09
A23	Kapistha	0.11	0.22	55.18	57.6	3.82	8.73	7.25	5.67	213.5	141	0.97	–0.78	0.03	0.09
A24	Bhatin	0.19	0.18	74.57	83.67	7.14	8.16	9.84	8.44	162.5	112.5	2.32	1.19	0.07	0.08
A25	Sutabai	0.14	0.18	37.57	49.87	3.93	6.36	6.54	7.33	305.5	184	–1.52	0.73	0.06	0.06
A26	Natungram	0.19	0.11	37.6	65.42	6.08	4.28	9.25	7.76	216	167.5	–2.19	1.24	0.06	0.04
A27	Sialdanga	0.19	0.19	37.52	91.66	6.07	7.66	9.46	6.13	216.5	138.5	–2.2	3.62	0.06	0.08

Note: SAR—Sodium Absorption Ratio; PI—Permeability Index; SSP—Soluble Sodium Percentage; MAR—Magnesium Absorption Ratio; TH—Total Hardness RSBC—Residual Sodium Bicarbonate; KR—Kelly's Ratio.

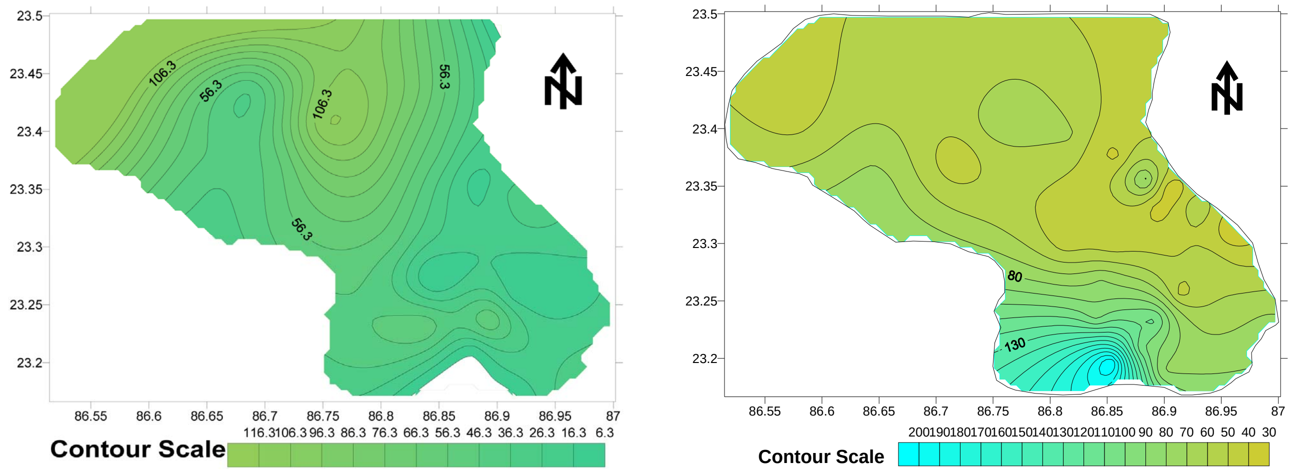
a large number of irrigation waters varying in ionic relationships and concentration. The permeability index is given by the following formula:

$$PI = \frac{\left(Na + HCO_3\right) \times 100}{\left(Ca + Mg + Na\right)}. \quad (7)$$

The plotted points has been shown that most of the points fall in the areas which are not good for irrigation **Figure 17**.

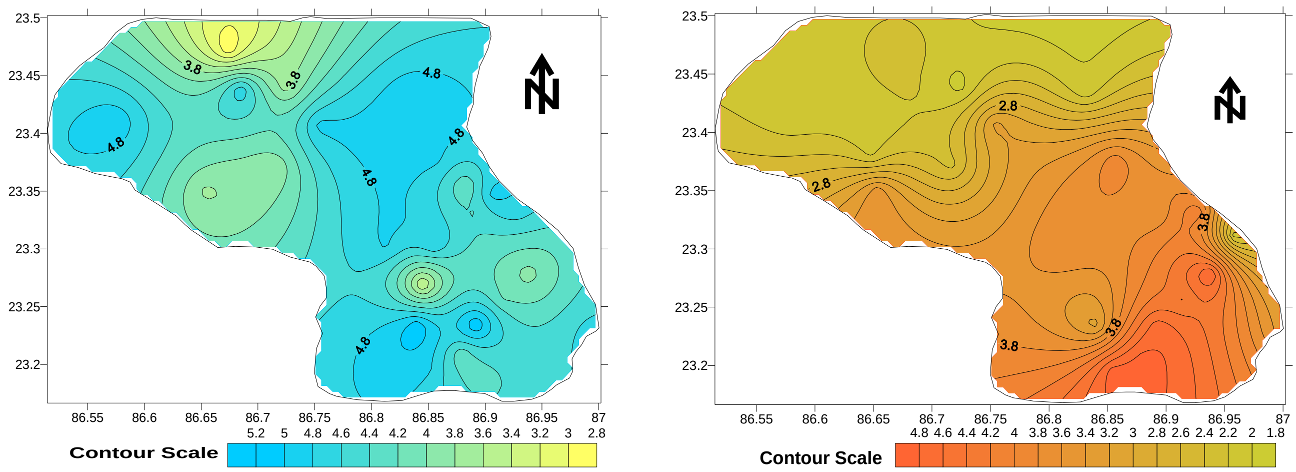
4.4. Domestic Suitability

Piper's [41] trilinear diagram is very important to assess the geochemical evaluation of groundwater. It consists of two lower triangular fields and a central diamond shaped field, all the three fields have scales reading in 100 parts. The percentage reacting values of the cations and the anions are plotted as a single point (according to the trilinear coordinates) at the lower left and right triangles, respectively. These are projected upwards parallel to the sides of the triangles to give a point in the rhombus. The point is represented by a circle whose area is proportional to the absolute concentration (actual pm) of the water. The water quality types can be qui ckly identified by the location of points in the different zones of the diamond-shaped field as shown in **Figure 18**.



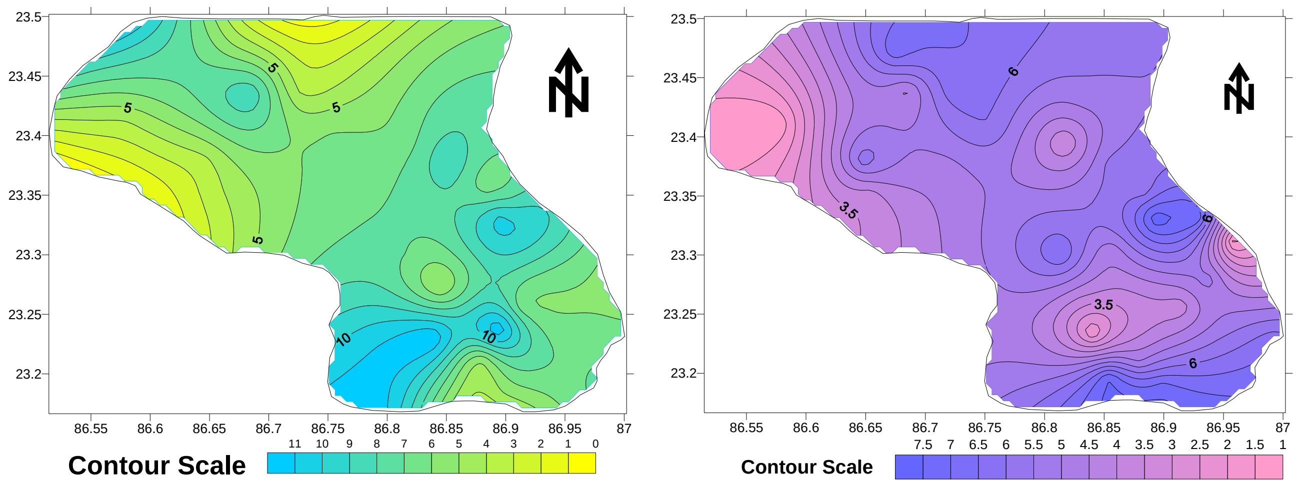
(a) (b)

Figure 11. Calcium contour map: (a) Pre-monsoon; (b) Post-monsoon.



(a) (b)

Figure 12. Magnesium contour map: (a) pre-monsoon; (b) post-monsoon.



(a) (b)

Figure 13. Sodium contour map: (a) pre-monsoon; (b) post-monsoon.

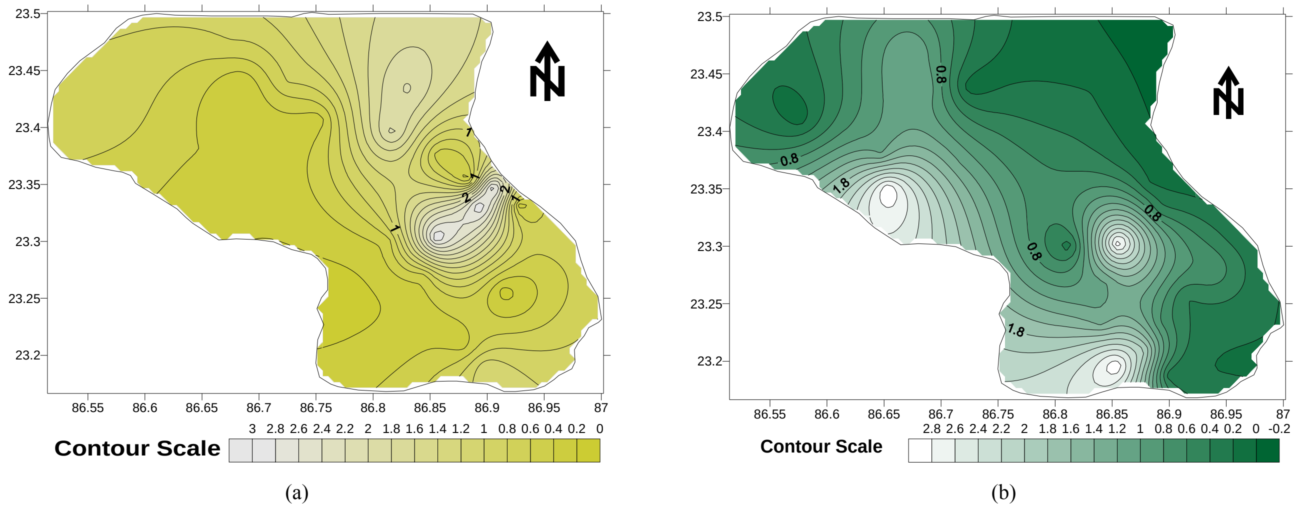


Figure 14. Iron contour map: (a) pre-monsoon; (b) post-monsoon.

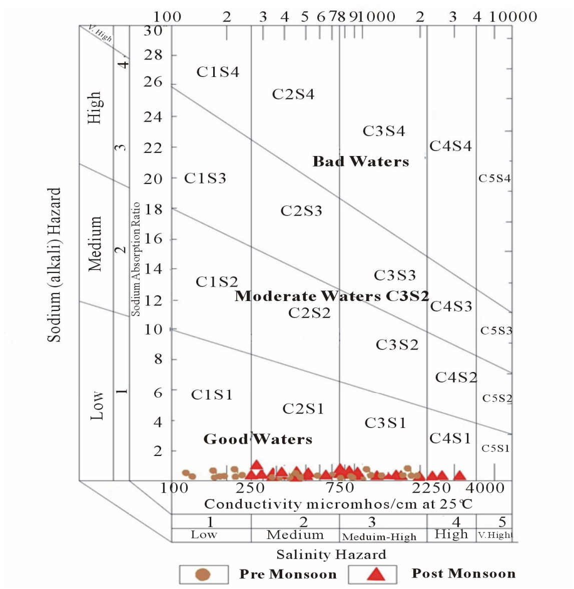


Figure 15. US salinity diagram.

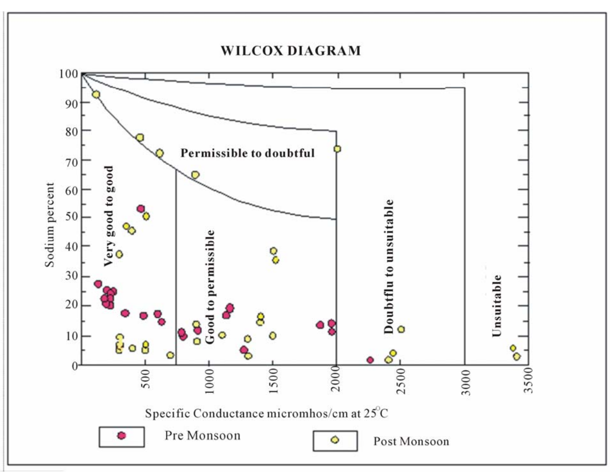


Figure 16. Wilcox diagram.

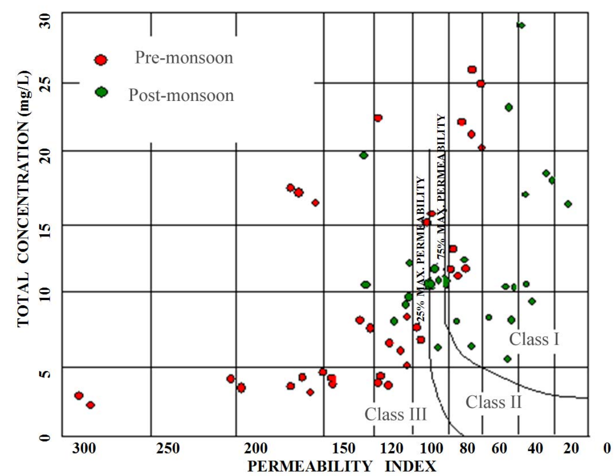


Figure 17. Permeability index diagram.

5. Conclusions

One of the most important use of groundwater is for drinking purpose. Hence, it is essential to ascertain the quality of groundwater because the presence of some minerals beyond certain limits may be unsuitable for drinking.

BIS, Government of India [42] has evolved a set of specifications for water to be used for drinking purposes. These are presented in **Table 3** and, when compared with the analyzed samples of the study area, it is found that the groundwater is within the safe category, except for few places where higher values of iron and total hardness exist. In general, it may be stated that groundwater of the study area falls within safe category. Hence, the study has helped to improve understanding of physicochemical parameters of the area for effective management and proper utilization of groundwater resources for better living conditions of the people. A continuous monitoring

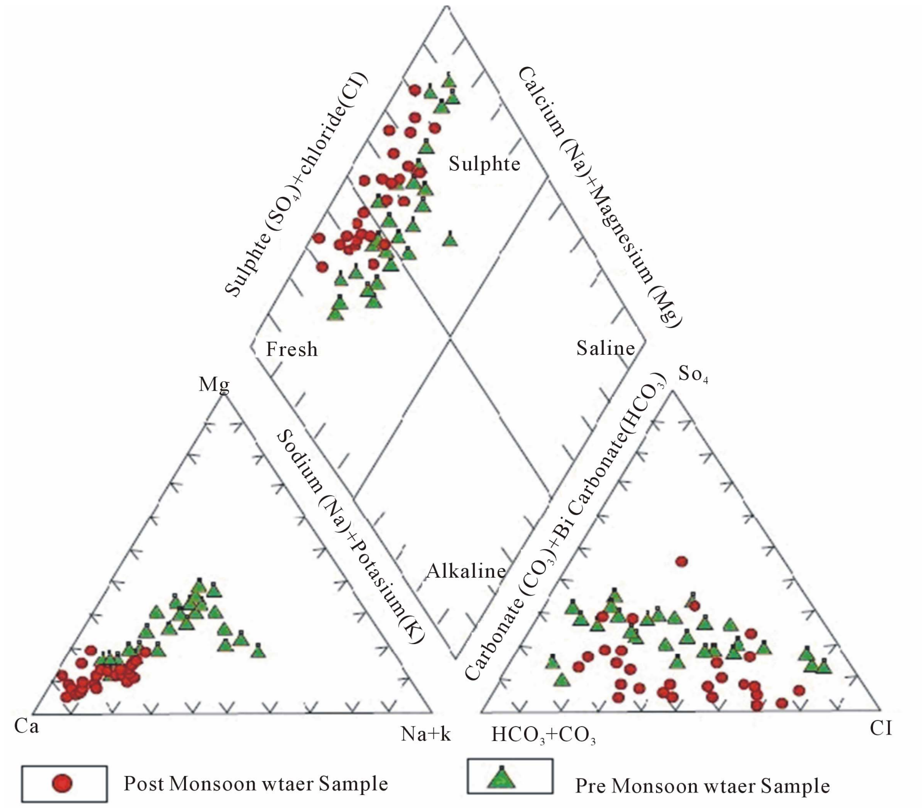


Figure 18. Piper trilinear diagram.

Table 3. Comparison of chemical analyses data with BIS, Govt. of India (pre-monsoon and post-monsoon, 2009).

Sample No.	Constituents	Limits of General Acceptability	Allowable Limit	Analysed Samples		Remarks	
				Pre-Monsoon	Post-Monsoon	Pre-Monsoon	Post-Monsoon
1.	pH	7 - 8	0.5 - 9.2	6 - 8	6.2 - 8.1	Within the limit	Within the limit
2.	Total Dissolved Solid (mg/L)	500	1500	83 - 1242	92 - 1365	Within the limit	Within the limit
3.	Specific Conductivity (at 25˚C) µS/cm	Below 780	-	140 - 1940	200 - 3400	Satyatan Primary School, Teghari, Gara, and Goaldanga having more than 800 µS/cm.	Within the limit
4.	Total Hardness (as $CaCO_3$) (mg/L)	300	600	90 - 1190	20 - 1070	Teghari and Gara having more than 1000 mg/L of $CaCO_3$. Satyatan Primary School has 870 mg/L of $CaCO_3$.	Teghari and Gara, Dwarkeswar River Bed having more than 1000 mg/L of $CaCO_3$.
5.	Calcium (mg/L)	75	200	6.39 - 113.74	30.06 - 214.23	Within the limit	Within the limit
6.	Magnessium (mg/L)	50	150	2.84 - 5.22	1.93 - 4.88	Within the limit	Within the limit
7.	Iron (mg/L)	0.3	1.0	0.1 - 3	0 - 3	Kamalpur, Sukhnibash, Jhatipahari has 3 mg/L of Fe and also Kanudi, has 1.2 mg/L of Fe in water	Kamalpur, Sukhnibash, Jhatipahari and Damankiari has 3 mg/L of Fe and also Kanudi, has 1.2 mg/L of Fe in water
8.	Chloride (mg/L)	200	600	10 - 660	20 - 580	Teghari and Gara has more than 600 mg/L of Cl in water	Within the limit

program of water quality is required to avoid further deterioration of the water quality of the study area.

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